The Balance Problem and its Relevance to Recycling of Rare Earths

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The rare earth elements (REE) are found in nature as mixtures of the different elements in certain ratios, which can show slight variations on the type of ore or the geographical location of the deposit. Bastnäsite and monazite are rich in the light rare earths elements (LREE), whereas xenotime and Chinese ion-adsorption clays are rich in the heavy rare earth elements (HREE). The general trend in the natural abundance of the rare earths is that the elements become scarcer with increasing atomic number Z (abundances decrease over the lanthanide series). Moreover, elements with an even atomic number Z are more abundant than elements with an odd atomic number (Oddo-Harkins rule). For example, cerium (Z = 58) is more abundant than its neighbors lanthanum (Z = 57) and praseodymium (Z = 59). Cerium is the dominating rare earth in ores rich in LREE and yttrium is the main rare earth in ores rich in HREE. The balance between the demand by the economic markets and the natural abundances of the REE in ores is a major problem for manufacturers of these elements. This is the so-called *balance problem* (or *balancing problem*).[1] The ideal situation is a perfect match between the demand and production of REE, so that there are no surpluses of any of the REE. This would result in the lowest market price for any of the REE, because the production costs are shared by all the elements. Unfortunately, this is not the case. Neodymium is high in demand for the production of neodymium-iron-boron magnets and this results in an overproduction of the other rare earths, and cerium in particular. The balance problem implicates that the rare earth industry has to find new applications for REE that are available in excess, or to search for substitutions for REE that have limited availability and that are high in demand. An example is partial replacement of neodymium in permanent magnets by praseodymium. Stockpiling of REEs is a possible answer to surpluses of some elements, but it is not the best option. REE markets are also permanently changing. Also diversification of the REE ores (i.e. use of other types of ores) can be a partial solution Neodymium has not always been the most critical elements on the REE market. As long as the rare earths were used as mixtures (e.g. as mischmetal) the balance problem was not existing. In the 1960s and the early 1970s, europium was the most critical REE because it has a low abundance and it was high in demand for use in phosphors for color television screens. In the 1970s and 1980s, samarium was the most critical REE, because of its use in samarium-cobalt permanent magnets. It is expected that dysprosium will be the critical REE of the future, because it has a limited availability and it is needed as an additive in neodymium-based permanent magnets for use in electric engines. So far, the balance problem has mainly been considered from the viewpoint of REE ores, and not from the viewpoint of REE recycling. It will be shown that REE recycling is not only of importance for securing the REE supply, but that is also offers a partial solution for the balance problem.[2,3]

References

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(3) K. Binnemans et al., *JOM* (2013) in press.